



## SolNet

PhD-scholarships and courses on solar heating

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# SOLNET - PHD-SCHOLARSHIPS AND COURSES ON SOLAR HEATING

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## Summary

SolNet, founded in 2006, is the first coordinated International PhD education program on Solar Thermal Engineering. The SolNet network is coordinated by the Institute of Thermal Engineering at Kassel University, Germany. The network offers PhD courses on solar heating and cooling, conference-accompanying Master courses, placements of internships, and PhD scholarship projects. A new scholarship project, “SHINE”, was launched in autumn 2013 in the frame work of the Marie Curie program of the European Union (Initial Training Network, ITN). 13 PhD-scholarships on solar district heating, solar heat for industrial processes, as well as sorption stores and materials started in December 2013. Additionally, the project comprises a training program with five PhD courses and several workshops on solar thermal engineering that will be open also for other PhD students working in the field. The research projects will be hosted by six different universities and five companies from all over Europe.

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## 1. Introduction

The focus of the “SHINE”-project will be on large solar heating systems and its’ new applications as well as new storage technologies and materials, i.e. sorption stores. Large scale solar heating systems are decisive to cover a major part of the European low temperature heat demand by solar energy and therewith to meet European policy aims. However, today only a negligible share of solar heating systems installed in Europe are large units due to manifold technical and socio-economic obstacles. The Initial Training Project will cover detailed experimental material-, component- and system studies, system integration analysis and numerical modelling and optimization, as well as chemical investigations on storage materials. A close cooperation with industry will ensure fast exploitation of the results. Within SHINE, the SolNet network offers a specialized and structured PhD course program about large solar heating systems. The participating institutes of the consortium of the EU initial training network “SHINE” and the topics of the individual PhD projects within the SHINE project are shown in Fig. 1.

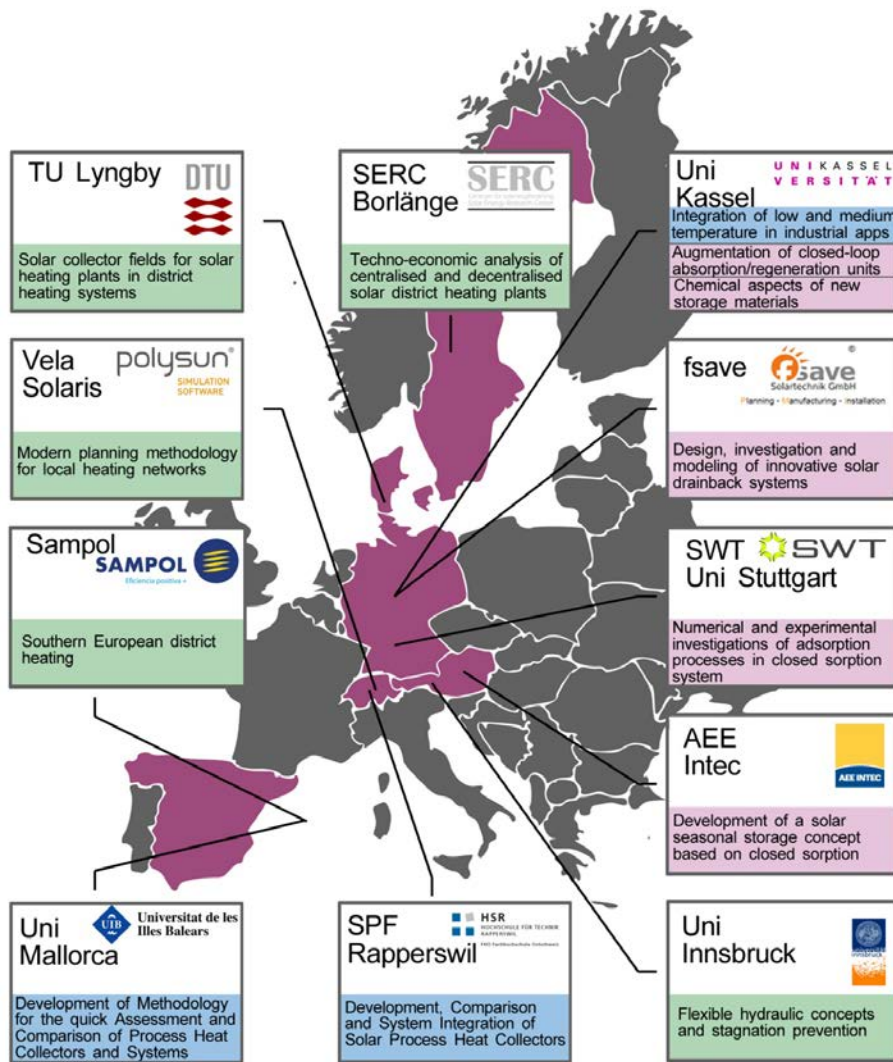


Fig. 1: Consortium and PhD topics in the framework of the Initial Research Training Project (ITN) “SHINE”

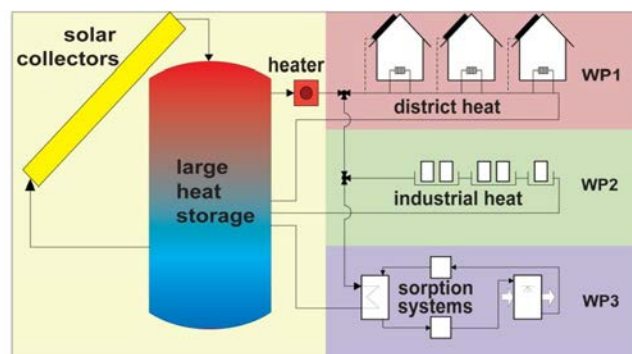


Fig. 2: Work Packages defined in the SHINE project.

## 2. Research objectives of the SHINE project

In the SHINE project universities and research institutes, manufacturers, software providers as well as district heating companies and industrial heat consumers work together on the development and implementation of large scale solar heating systems. 13 PhD students work in one of three work packages, i.e. “Solar District Heating”, “Solar Heat for Industrial Processes”, and “Sorption Processes and Materials”, Fig. 2.

## **Work package 1 – Solar District Heating**

### **a) Research objectives in solar district heating**

Research objectives of the first work package are to optimize complex hydraulics and operation strategies in terms of flexibility to serve variable loads and in terms of overall collector efficiency, pressure drop and safety of collector stagnation for different boundary conditions. Moreover, the aims are to analyze the advantages and disadvantages of centralized and decentralized solar collector fields in district heating networks and to derive the technological and economic boundary conditions for profitable operation. Both de-centralized feed-in (connection on primary side) and district heat augmented systems (connection on secondary side) will be covered. Additionally, the work package will propose design and operating strategies for district heating networks that supply both, heating and cooling demands and to show advantages and disadvantages of central distribution of cooled fluid versus distribution of heated fluid with local production of the cooling effects.

Five PhD projects are carried out in the framework of the work package and one additional PhD project on drain back systems is also associated to it.

### **b) Individual PhD projects on solar district heating**

The PhD students evaluate data from field tests of solar heating systems connected to district heating networks and use them for model development and validation. Most of the students work with the simulation tool TRNSYS, on the extension of existing models to the needs of district heating applications, for example taking into account multiple collector fields, loads, etc.. Additional tools will be developed in order to consider some aspects, like flow distributions in collector field hydraulics, in more detail. Moreover, tri-generation plants will be investigated to take into account southern European conditions.

The topics of the individual PhD projects are

- Solar collector fields for solar heating plants in district heating systems (Federico Bava, Technical University of Denmark, DK)
- Flexible hydraulic concepts and stagnation prevention (Alireza Shantia, University of Innsbruck, AT)
- Modern planning methodology for local heating networks (Artem Sotnikov, Vela Solaris AG, CH)
- Techno-economic analysis of centralised and decentralised solar district heating plants (Christian Nielsen, Högskolan Dalarna, SE)
- Southern European district heating (Nicolás Pérez-Mora, Sampol, ES)
- Design, investigation and modeling of innovative solar drainback systems (Yoann Louvet, Kassel University, DE)

### **c) System monitoring of solar district heating plants**

The propagation of district heating networks is very different in different European countries. In the Scandinavian Countries, mainly Sweden and Denmark, district heating is wide spread also on a large scale and there is already a long tradition also to implement solar heating systems into district heating. Moreover, in Denmark, the area of solar heating plants supplying district heating networks with heat is expected to double by the end of 2015, compared to 2013. In such a scenario, even a small efficiency improvement may lead to a large increase in the overall energy production in absolute terms. For this reason optimization of the solar collector field design and control strategy plays a key role. In Sweden, both centralized systems with collector field sizes of several thousand square meters and de-centralized systems with small collector fields installed on individual houses that feed into district heating networks are investigated.

As many large scale solar heating systems connected to district heating networks are already in operation in Sweden and Denmark, already several field projects are available and existing systems in Sweden as well as in Denmark will be closely monitored and analyzed, some of them in co-operation with the associated

partner of the SHINE project, the Danish company ARCON Solar A/S. Moreover, several Central European systems will be evaluated with the network of the Swiss company Vela Solaris who is involved in the project as full partner.

Moreover, experimental measurements will be carried out at the different University test facilities, like system test rigs, as well as solar collector and hydraulic test rigs.

The first system to be analyzed is a solar-assisted block heating system in Vallda Heberg outside Gothenburg, Sweden (Nielsen, Hägermark and Dalenbäck, 2014). The network consists of low-energy houses and apartments in a new residential area. The hot water, which is distributed in twin-pipes, is used for space heating and for direct hot water tapping. Evacuated tube collectors are installed at the boiler central and flat-plate solar collectors are connected to sub-stations in several locations of the area.

In contrast, in Southern Europe solar thermal energy is often used for space heating for only a few months per year. Therefore solar cooling is a suitable option to increase the yield of solar thermal plants that support tri-generation power plants. In this kind of facilities, solar heating and cooling can be integrated in the district network management, with the aim to optimize energy and economic system performance.

In order to gather experience specifically related to large drain systems, at least three drain back systems with a collector area larger than 100 m<sup>2</sup> will be monitored in detail and analyzed.

#### **d) System Modelling and Simulation tools for solar district heating**

Most PhD students of the work package will work with the simulation tool TRNSYS. Based on the real systems, dynamic models are built to predict performance of similar systems. In particular, new models will be developed to investigate the heat production of other heat sources. Pipe losses and loads of a district heating network will also be included in the models to better understand the technological and energetic benefits and draw-backs of installing solar collectors in different parts of a district heating network. Other models will take into account in detail the flow distribution in the collector field, shadow effect from one row to another, heat losses from the pipes in the solar collector loop, heat capacity of the solar collectors, as well as influence of flow rate and tilt angle on the collector efficiency. The validated models will be used to optimize the field in terms of hydraulic configuration and control strategy.

Up to now, a model able to evaluate the pressure drop in large scale solar collectors with the same design as that used in Danish solar heating fields has been developed and successfully validated against experimental measurements carried out on two different Arcon collectors (models HT 35-10 and 28-8). Additionally, the influence of flow rate, tilt angle, solar collector fluid type (propylene glycol/water mixture and water) and the presence of a convection barrier has been studied through efficiency and incidence angle modifier testing on two Arcon collectors (models HT-SA 35-10 and HT-A 35-10).

Mostly, existing TRNSYS models postulate that the hydronic system can constantly deliver the expected flow rates at different points of the circuit. However, considering uneven flow distributions at full and part loads, the transient behavior of control tools installed in the system has a high impact on the system performance. Dynamic thermal interaction between the system components imposed by controlled parameters outside hydronic system boundaries, like room temperatures and humidity, also taking into account transient boundary conditions like the solar irradiation or ambient temperature, will be evaluated with a novel tool that will be developed in the framework of the research project.

Another simulation tool used in the project is Polysun, which is written in Java programming language. Today, the Polysun application range includes renewable energy systems as well as detached buildings of various sizes. The first step of the project is extending the current Polysun building model in order to cover multiple residential units. The main goal of the PhD project is to extend the code and to develop and implement building and geothermal probe models in order to cover a range of district heating system applications. Model validation, calibration and result comparison will be carried out with monitored data and with the TRNSYS simulation software. Furthermore, an advanced controlling strategy using a new functionality of the Polysun simulation software will be implemented to optimize the district heating systems performance.

#### **e) Evaluation targets and methodologies on solar district heating**

Besides technical questions, the socio- and business-economic feasibility of implementing solar heat in a system will be evaluated. The economic evaluation should include investment, operational and maintenance costs of different heating technologies, as well as location specific taxes, subsidies, energy and building site prices. The influence of fluctuating electricity prices and the uncertainty of the development of future prices will also be studied.

Moreover, a modular tool will be developed for the calculation of fluid flow and pressure drop as well as thermal losses/gains in complicated networks with combination of series, parallel and grid connections considering the control characteristics of pumps, valves and heat exchangers. With this tool, the possibility for adaptive hydraulics for space heating systems as well as solar thermal systems will be examined. In the first step, the program should deal with constant mass flow in systems with various valves and hydraulic circuits, while in the second phase, it ought to be able to analyze the dynamic response of the systems due to control characteristics.

In order to improve district network management strategies for tri-generation plants, information on thermal and electric load and the energy prices are necessary, to avoid energy wastes or low economic feasibility. Besides the detailed knowledge of the power plant, an accurate energy consumption estimation and energy price forecast are needed in order to create a proper energy curve fitting. A plant simulator will be developed that includes forecasted information to adjust thermal and electric generation curves in order to optimize the energy and economic system performance.

#### **f) Investigations on large drain-back systems**

As an additional topic, a project on drain-back systems is involved in this work package. In drain-back systems the collectors and the outside piping are emptying by gravity when the solar heating system is not in operation, in order to avoid the need of anti-freeze liquids in the solar collector loop. The solar fluid is then replaced by air. Drain-back systems allow the use of water as collector fluid. This renders the installation safer thanks to passive overheating and freezing protections, and thus reduces the need for maintenance. On the other hand, drain back systems require a careful installation of pipework, and corrosion is an issue especially for open systems.

The aim of the PhD project is to develop a fairly safe and cost effective drain back concept. A novel test facility will be erected and field test monitoring will be carried out in order to investigate the proper drain-back capability of the installation (filling, draining...). Finally numerical simulations are envisioned using TRNSYS software, with the help of the various collected data.

### **Work package 2 – Solar Heat for Industrial Processes**

Throughout the world, lower grade thermal energy (50-150 C) is used for a countless number of industrial applications. Additionally, many other processes require heat supply at a medium temperature range between 80° and 250° (Sallaberry, 2014), which are usually not covered by technologies from more established solar technologies such as domestic heat or concentrating solar power.

As climate change remains an ever present threat, efforts must be made to decrease emissions along all energy consuming avenues. Often overshadowed by electricity, the heat demand within the industrial sector is significant, of which most can be met by renewable sources. Prior studies have indicated that a significant fraction of this consumption can be realistically supplanted with solar heat energy. Therefore, there is a growing need for reliable and cost-efficient systems in this area. Until now, surveys have shown that relatively few industrial systems exist worldwide and knowledge dissemination in this field is low.

#### **a) Research objectives**

Research objectives of this work package are to reduce the large planning efforts (requiring expert knowledge) for system integration into existing heating systems for new applications, especially for industrial processes. Therefore, the aim is to develop tools and methodological approaches which industries

can use to determine the feasibility of a solar thermal system within their processes. These tools include TRNSYS simulations which will determine the recommended solar integration point, solar system performance, fuel savings, and economics, all based on defined inputs of the facility location, heat demand profile, and fuel consumption. This tool is to continuously be updated with realized projects to ensure the closest agreement between simulations and the real world. When completed, this work will help to lower risks and costs associated with solar thermal projects and to encourage a rapid adoption of using solar heat for industrial applications.

In tandem with process level analysis, the supply level is identified for optimization potential of solar thermal systems for industrial processes by analyzing the effect of parameter variation. This will be realized by detailed studies of existing plants in Switzerland in combination with simulation analysis of the same focusing on control issues, heating up, overheating, stagnation, and feasibility of collector types. Furthermore, economic indicators may be developed in order to improve the comparison of solar process heat systems and indicate optimization possibilities.

Moreover, solar collectors will be further developed that can efficiently and cost-effectively provide operation temperatures of up to 250°C to be used for industrial processes. Process heat collectors often represent adapted versions of their low and high temperature counterparts or are even based on completely new designs. The application must also fit the individual needs of the customer including limited space, roof-top installations and variable load profiles all of which lead to a very site-specific installation. Given such a large and ever increasing variety of different collector concepts, a methodology is needed that allows to quickly determine the most economically reasonable design regarding the desired application. This methodology might one day evolve to an established tool for industry to promote dissemination of process heat technologies.

#### **b) Individual PhD projects on solar assisted industrial processes**

Three PhD projects are involved in the work package. The topics of the individual PhD projects are

- The integration of low and medium temperature solar heat for use in industrial applications (Steven Meyers, Kassel University, DE)
- Development, Comparison and System Integration of Solar Process Heat Collectors (Jana Möllenkamp, University for Applied Sciences Rapperswil, CH)
- Development of a Methodology for the quick Assessment and Comparison of Process Heat Collectors and Systems (Julian Hertel, Balearic Islands University, ES)

#### **Work package 3 – Advanced Storage Concepts and sorption processes**

Efficient solar heating storages are decisive for efficient large scale heat supply systems. To reach a higher energy density than in water stores, various solid and liquid sorption materials as well as sorption processes will be investigated.

Additionally, low temperature heat can be used to run absorption cooling machines and open liquid desiccant systems. As the same heat and mass transfer processes are relevant, the work package covers both applications, sorption stores as well as sorption drying and cooling processes.

#### **a) Research objectives on sorption processes**

In work package 3, PhD students will investigate adsorption and absorption processes in closed loop or as open desiccant systems with numerical and experimental means, with the aim to attain a better understanding of the heat and mass transfer processes and to increase the performance of the processes.

Two of the PhD projects will focus on the adsorption/desorption process of water steam in zeolites. This material pair provides a distinctly higher energy density compared to that of water, and the possibility of loss-free energy storage over months. One of the main objectives is to develop and prove a seasonal thermal storage concept with high solar fraction based on the sorption principle.

Numerical investigations and laboratory experiments will be carried out in co-operation with an associated research project.

In another PhD project the heat and mass transfer phenomena in absorption cycles will be investigated. Among several parameters that affect the heat and mass transfer, there will be a focus on the role of surface modifications and sorption materials used in an absorption cycle.

Furthermore, chemical investigations will be carried out on sorption materials suitable for the applications. The objectives are to improve the performance of sorption materials by means of chemical modification and combination of fluid solid hybrid materials and to further develop sorption processes that can be utilized for drying, heating or cooling applications.

#### **b) Individual PhD projects on sorption materials and processes**

The topics of the individual Phd projects are

- Numerical and experimental investigations of the adsorption processes in a closed sorption system (Dominik Radler, Stuttgart University, DE)
- Augmentation of closed-loop absorption/regeneration units (Federico Lonardi, Kassel University, DE)
- Development of a solar seasonal storage concept based on closed sorption (Verena Schubert, AEE INTEC, Gleisdorf, AT)
- Chemical aspects of new storage materials (Kristijan Krekić, Kassel University, DE)

#### **c) Numerical and experimental investigations on an adsorption system**

A suitable model for the mass, momentum and energy balances of an adsorption process will be developed. Closed adsorption systems work at negative pressures due to the attracting forces caused by zeolite. Therefore the flow characteristic is different than the flow characteristic under atmospheric pressure. In a first step, there will be an evaluation whether or not conventional models, i.e. Darcy's law and Brinkman's law, are applicable in negative pressure environments. Moreover, the degree of detail for the energy balances will be defined. In order to simplify the numerical model, it will be considered to assume equal temperatures of the adsorbent and adsorbate or additionally of the steam. The mathematical model will be verified by experiments and simulations will be carried out with different materials and reactor designs, with the aim, to develop a simplified model of a closed adsorption system.

Several experimental apparatuses will be built from a small scale of 80ml adsorbent volume up to a bigger scale of 50l of adsorbent volume.

Moreover, a first large-scale demonstration prototype of a closed adsorption energy storage will be built-up in the laboratory and will be tested under real conditions by using optimized control strategies. The most promising control strategy will be found by numerical simulations using the dynamic simulation environment TRNSYS. The whole system will be studied concerning prototype performance and the total solar fraction savings, respectively. Based on detailed measurement analyses a simulation model validation and optimization calculations will be carried out.

#### **d) Investigations on sorption materials**

Poor heat transfer and problems in close packing are major obstacles for the application of adsorption

materials in long term storages (Janiak and Henninger, 2013). Therefore, a new approach is to combine liquid and solid materials. The solid phases include porous materials like silica gel, zeolites, metal-organic frameworks, etc., while hygroscopic liquids (ionic liquids, glycols, etc.) are used as absorbents and heat transfer fluids. Isothermal calorimetric titration of sample mixtures with water is carried out. First results

**Tab. 1: Water adsorption enthalpies of some solid used in work**

| Name                           | $\Delta H_{ads}$ [kJ/kg] |
|--------------------------------|--------------------------|
| Silica gel (SiO <sub>2</sub> ) | 66                       |
| Zeolite 13XBF                  | 900                      |
| MOF HKUST-1                    | 480                      |



indicate that combinations of weakly adsorbing solids, like silica gel, with strongly absorbing liquids, like ionic liquids, show no improvement. However, a proper combination of fluid and solids may show desirable properties. In table 1 adsorption enthalpies of solids that will be further investigated are summarized.

### 3. Training program

Tab. 2 shows the courses within the SHINE project as well as the dates, hosts and location. Before the start of the SHINE project, nine PhD level courses had been carried out at member universities. During the project, five more will be completed. Of these three have already taken place in the first half of 2014. These are open to all PhD students, although only SHINE students are guaranteed places. The number of students generally ranges from 20 to 30, the courses being a networking forum for young researchers in solar thermal.

The training events generally contain the following parts:

- Student work at home university or companies (including preparation of presentations and reports)
- Plenary and work package meetings of the SHINE project
- A training module about a specified topic (usually 4 days)
- Additional workshops and/or special lectures/presentations by associated or other industry partners
- Technical visits to build examples and/or factories

**Tab. 2: Courses hosted within the SHINE project together with their dates, hosts and locations.**

| <b>Date</b>   | <b>Host (location)</b>                          | <b>Title</b>                                                                                                                                                                              |
|---------------|-------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| February 2014 | Universität Innsbruck (Innsbruck. AT)           | <b>System Integration of Solar Thermal Plants:</b><br>Characterization. Guidelines. Analysis of Applications. Hydraulics. Control Systems. Dimensioning and Optimisation. Design Exercise |
| February 2014 | Högskolan Dalarna (Innsbruck. AT)               | <b>Dynamic simulation of energy systems:</b><br>Simulation tools. assumptions and simplifications at component and system level. planning of simulation studies. individual project.      |
| May 2014      | Technical University of Denmark (Lyngby. DK)    | <b>Heat storage for solar heating systems:</b><br>Modelling. Experimental Investigations. Seasonal storage. Stratification in water stores. PCM. Thermo-Chemical.                         |
| Spring 2015   | Universitat de les Illes Balears (Mallorca. ES) | <b>Solar collectors:</b><br>Heat Transfer and Optics. Solar Collector Modelling and Testing. High Temperature Flat-Plate Collectors. Building Integration of Solar Collectors.            |
| Spring 2016   | Kassel University (Kassel. DE)                  | <b>Applications for large solar heating systems:</b><br>District heating. industrial Process Heat and Sorption Processes                                                                  |

#### 4. Industry Partners

There have been long term co-operations in the past between universities and private sector partners, which is now intensified through the SHINE project. The private sector hosts five PhD students over the full duration. They supply the infrastructure (laboratory, workshop) for experiments, an adequate work space, technical infrastructure, as well as intensive supervision for the PhD students as a host or for a secondment stay.

| Company                           | Role               | Country     | Competences                         |
|-----------------------------------|--------------------|-------------|-------------------------------------|
| Arcon Solar A/S                   | Associated partner | Danmark     | Manufacturing, planning, installing |
| fsave solartechnik GmbH           | Full partner       | Germany     | Manufacturing, planning             |
| Tecnologia Solar Concentradora SL | Associated partner | Spain       | Measurement                         |
| Vela Solaris AG                   | Full partner       | Switzerland | Numerical modeling, planning        |
| Sampol Ingenieria y Obras S. A.   | Full partner       | Spain       | Manufacturing, planning             |
| Solarus                           | Associated partner | Sweden      | System integration                  |
| Siko Solar                        | Associated partner | Austria     | Manufacturing, planning, installing |
| SWT                               | Full partner       | Germany     | Technology development, planning    |

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